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REPLY TO ANGELO: CHANGES IN THE FLORA OF CONCORD, MASSACHUSETTS

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Angelo (2014a, b) recently wrote two critiques of our research (work we did with several collaborators) documenting declines in the abundance of plant species in Concord, Massachusetts, and linking those changes in abundance with warming temperatures (Willis et al. 2008; Primack et al. 2009). We and our collaborators provided detailed responses (Primack et al. 2014; Willis & Davis 2014) to the first critique (Angelo 2014a). In his second critique, Angelo (2014b) added detail and new comments. Several points Angelo (2014b) makes have merit and suggest the need for a new formal flora of Concord. Further, his analysis has improved our data set. However, his main criticisms are based on misunderstandings of our goals, methods, and conclusions. Moreover, we believe our main findings — i.e., that many species in Concord, Massachusetts, are declining in abundance and that these changes in abundance are in part linked with warming temperatures — still hold true.

Our research (Willis et al. 2008; Primack et al. 2009) was not intended to produce a flora of Concord but rather to describe general patterns of change over time for a defined subset of plant species in Concord — i.e., species that past botanists such as Alfred Hosmer and Henry David Thoreau observed. Our community-level approach and statistical analysis allowed our results to be robust despite incomplete or imperfect information on individual species, including unclear taxonomy and other mistakes pointed out by Angelo (2014a, b) (some of which we think are valid, and some of which we disagree with). The "noise" that would have been caused by this imperfect information would have made it less likely that we would have detected the patterns that we did find — patterns that are consistent with results in many other locations.

In addition, our community-level approach — which was novel at the time — and our conclusions are consistent with the findings of others; our field and data-analysis methods are comparable to other field studies (e.g., Robinson et al. 1994; Leach & Givnish 1996; Lavergne et al. 2006). For example, other floras in urban and suburban areas of eastern Massachusetts have documented declines in the abundance of native species (Bertin 2002; Standley 2003), although the number of native species in Worcester County, a relatively large and rural area, does not appear to be declining (Bertin 2013). Studies in New England and a broader meta-analyses of over 1300 species responses globally have linked warming temperatures with shifts in species ranges (Beckage et al. 2008; Chen et al. 2011; Bertin 2013), and two separate meta-analyses have confirmed that changes in phenology are indeed linked with plant performance in many locations (Cleland et al. 2012; Wolkovich et al. 2013).

Below we provide brief responses to nine of the main points made by Angelo (2014b) about our work. For more detailed responses to most of these and other points, we refer you to our previous responses (Primack et al. 2014; Willis and Davis 2014).

1. Assertion: One of the early floras we used to assess changes in the abundance of plants included Concord and vicinity, whereas our surveys covered only Concord, creating a mismatch between the study areas.

Our response: We compared our survey results with data from three past botanical treatments, two of which were confined to Concord. Comparisons with all three show similar patterns of species decline.

2. Assertion: We did not thoroughly search of all of Concord; we did not search private, unprotected lands in particular; and we lacked the skill to find plants.

Our response: We thoroughly surveyed the plants of Concord over a five-year period. Our surveys involved several people searching for several days per week, with some additional fieldwork during the past seven years. We also sought advice from local botanists, including Angelo, about the locations of locally rare plants. We surveyed private and public lands, including private, unprotected areas. We have strong backgrounds in botany and have extensive experience of carrying out botanical surveys and statistical analysis.

3. Assertion: Some of species that we could not find do still occur in Concord, and some of the species are more common than we reported.

Our response: We have always acknowledged that additional fieldwork will result in people finding localities for populations we could not find (Primack et al. 2009). The additional locations reported by Angelo and others, some of which we have also found, represent a small percentage (less than 7%) of the species that we report as declining, and do not significantly affect the overall patterns in our findings.

4. Assertion: We cannot know the meaning of terms used by past botanists — i.e., what "common" or "occasional" meant in terms of absolute abundance. In particular, Hosmer (1903), one of the historical botanists we relied on in our study, was biased toward categorizing species as "common," whereas our undersampling biased us to categorize species as currently uncommon or rare. Thus, it was not surprising that we found that species were declining in abundance.

Our response: Even though past botanists did not define their terms for frequency of occurrence, it is reasonable to assume that individual botanists used the terms consistently, making our flora-wide comparative analysis of changes in *relative* abundance appropriate. Additionally, our results were consistent when comparing our survey results with those of three separate past botanical surveys, suggesting that our conclusions are not caused by a systematic bias between our survey and just one of the historical surveys.

5. Assertion: We erroneously assume that species found at just one site are invariably destined for extinction.

Our response: This is a misstatement of our conclusions. We are not stating that all rare species are destined for extinction. Rather, we simply point out that rare species or species with small populations face a much higher probability of local extinction, a basic tenant of population biology that has been confirmed by numerous studies.

6. Assertion: Accounting for factors other than climate change in our statistical analyses would reduce the relationship between climate change and declines in abundance that we found.

Our response: We used standard statistical analyses designed to account for the simultaneous effects of multiple ecological factors other than those associated with climate change, including habitat, deer browse preference, and status as a native or non-native species (Willis et al. 2010). Furthermore, we made clear in our original discussion and our response that these additional factors have likely impacted the flora of Concord in conjunction with the effects of climate change.

7. Assertion: We found that populations appeared to decline most over the past 30-40 years, while temperatures did not warm substantially over that period compared to warming over the previous 100 years.

Our response: Population sizes do not have to fluctuate in synchrony with temperature for population decline to be related to temperature. In our case, we found an indirect relationship — species that declined tended to have flowering times that did not track changes in temperature and tended to have more northerly distributions. Bertin (2013) also found evidence of the effects of climate change, with northern species disproportionately declining in Worcester County. Even though temperatures have generally been warming in eastern Massachusetts for the past 160 years, the increases have been cumulative such that the past three decades have been the warmest overall, with many record high temperatures.

8. Assertion: We included inappropriate species in our study, including non-native species, species of uncertain taxonomy, and species known to be declining for reasons other than climate change.

Our response: Angelo (2014b) identified some problem species in our data set, which we are appreciative of. However, we disagree with many of his assessments regarding which species were appropriate to include or exclude. Given that our analysis took a community-level approach, and given that multiple factors can affect the abundance of a particular species simultaneously (e.g., deer grazing, air pollution, and a warming climate), we included all available species. We explicitly accounted for many factors that might affect their abundance — including non-native status, deer browse preference, and habitat — in our statistical analysis.

9. Assertion: If climate change were driving declines in the abundance of certain species, those declines would be widespread. However, many species that we found to be declining in abundance in Concord do not appear to be declining in abundance in two locations relatively close to Concord, the Middlesex Fells (Hamlin et al. 2013) and Worcester County (Bertin 2013), and therefor should be excluded from the analysis.

Our response: This is an interesting point. However, the abundance of each species is affected by many factors, and the balance of these factors varies from place to place (Cleland et al. 2012). In particular, each place has its own distinctive geology, soils, topography, history of past land use, and current intensity and types of human activity. Consequently, excluding species from our analysis of changes in abundance in Concord because they are not declining elsewhere is not appropriate.

Investigations of changes in the abundance of species are critical to conservation biologists and protected area managers charged with preserving biodiversity. Thus, we very much support continued investigations related to this topic and have made the data resulting from our work freely accessible for studies like those of Angelo (2014a, b) and others (e.g., Diez et al. 2012; Wolkovich et al. 2012; Wolkovich et al. 2013). In this case, Angelo (2014a, b) appears to agree that the number of native species in the Concord flora is declining, but he disagrees on the pace of the declines and the role of climate change. After considering his points, we find that our results are still valid, and his criticisms are based on a misunderstanding of our methods, goals, and statistical tests. More research, including a formal flora of modern Concord, if done, will continue to improve our understanding of how Concord's flora has changed since the observations of Thoreau and other botanists.

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